PART II: PROPOSED CLIMSAT MISSION

7. Climsat Rationale

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A brief but comprehensive overview of the Climsat rationale is provided by the Executive and Workshop Summaries (pp. vii-xv). More detailed information is provided in the science papers (Sections 1-6) above and in the instrument and data sampling papers (Sections 8-12) below. Here we summarize reasons for the Climsat proposition, and cover some aspects not treated in the other sections. We also stress the need for certain climate monitoring other than that supplied by Climsat, especially solar irradiance, and we stress the complementarity of Climsat monitoring to plans for detailed EOS measurements.

Table 7.1 summarizes the fact that existing and planned observations will not provide measurements of most climate forcing and feedback parameters with the accuracy needed to measure plausible decadal changes. In this table a dash in the second column signifies the absence of calibrated data meeting the requirements in the mid 1990s. Stratospheric water vapor and aerosol requirements are not met, for example, even though the present SAGE II instrument on the ERBS spacecraft measures those two parameters accurately, because ERBS is not expected to last more than a few years and it does not provide global coverage. We stress the imminence of a potential data gap even of those parameters, such as solar irradiance and stratospheric aerosols, for which monitoring capability has been proven and currently is in place.

We find that most of the missing global climate forcings and feedbacks can be measured by three small instruments, which would need to be deployed on two spacecraft to obtain adequate sampling and global coverage. The monitoring must be maintained continuously for at least two decades. Such continuity can be attained by replacing a satellite after it fails, the functioning satellite providing calibration transfer to the new satellite. Certain complementary monitoring data are also needed, including solar monitoring from space, in order to fully meet requirements for monitoring all the climate forcings and feedbacks. The complementary data needs are discussed toward the end of this section.

We summarize the proposed Climsat measurements and compare the expected accuracies to those which are needed to analyze changes of the global thermal energy cycle on decadal time scales. We stress the need to get broader participation of the scientific community in the monitoring and analysis activity. Finally, we discuss related climate process and diagnostic measurements.

Climsat Measurements

Measurements by the three proposed Climsat instruments cover practically the entire thermal and solar spectra, as summarized in Fig. 7.1. This is a crucial characteristic of the proposed measurements, because it means they should be capable of providing information on climate "surprises" as well as the climate forcings and feedbacks which we already know about. All radiative forcings and feedbacks operate by altering the solar or thermal spectra in some way.

The Climsat instruments are designed to exploit the full information content in the emitted thermal and reflected solar spectra. In the thermal region information is contained primarily in the high resolution spectral variations of the radiance (Conrath *et al.*, 1970; Hanel *et al.*, 1972b; Kunde *et al.*, 1974; Clough *et al.*, 1989b). On the other hand, because incident sunlight is unidirectional, the reflected solar radiation is in general strongly polarized, and the polarization is highly diagnostic of aerosol and cloud properties (Hansen and Travis, 1974; Coffeen and Hansen, 1974).

MINT (Michelson Interferometer) covers the spectral range 6-40 μm, the long wavelengths being important for defining the water vapor distribution. Its high spectral resolution and high

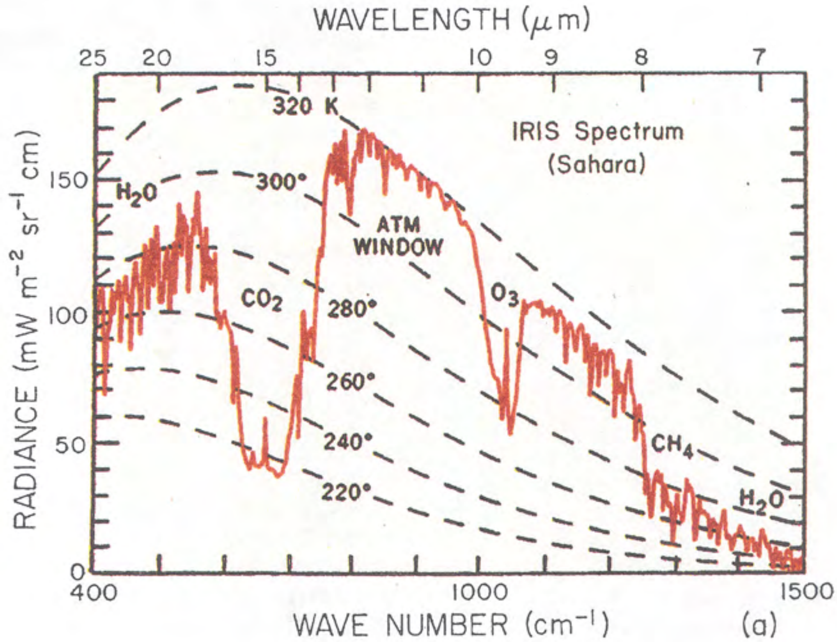
TABLE 7.1. **Principal Global Climate Forcings, Radiative Feedbacks, and Diagnostics**

	1996 Calibrated Source Meeting Requirements	Proposed Climsat Contributions	Needed Complementary Data
Climate Forcings			
Greenhouse gases			
CO_2, CFCs, CH_4 and N_2O	G	—	—
O_3 (profile)	—	SAGE	NDSC
stratospheric H_2O	—	SAGE	—
Aerosols			
tropospheric	—	EOSP (SAGE)	Surface reference network
stratospheric	—	SAGE (EOSP)	Surface reference network
Solar Irradiance	—	—	ACRIM, SOLSTICE
Surface Reflectivity	—	EOSP	—
Radiative Feedbacks			
Clouds			
cover	O	MINT/EOSP	—
height (temperature)	—	MINT/EOSP/SAGE	—
optical depth	—	MINT/EOSP	—
particle size	—	MINT/EOSP	—
water phase	—	MINT/EOSP	—
Lower tropospheric H_2O (profile)	O, W	MINT	Reference radiosonde
Upper tropospheric H_2O (profile)	—	SAGE/MINT	Reference radiosonde
Sea Ice Cover	O	—	—
Snow Cover	O	—	—
Climate Diagnostics			
Temperature			
upper air	W, O	MINT	Reference radiosonde
surface air	W	—	—
sea surface	S, O	MINT	—
Ocean			
internal temperature	—	—	Continuation of WOCE, accoustic tomography
surface salinity	—	—	Continuation of WOCE
transient tracers	—	—	Continuation of WOCE
Radiation Budget			
top of atmosphere	—	—	SCARAB, CERES
surface	—	—	WCRP Baseline Network

Data source key: O = operational satellite system, X = experimental satellites (e.g., TRMM), W = operational weather station network, G = other ground stations and aircraft, S = ships and buoys. SAGE = Stratospheric Aerosol and Gas Experiment. EOSP = Earth Observing Scanning Polarimeter. MINT = Michelson Interferometer.

wavelength-to-wavelength precision provide the essential ingredients for accurate long-term monitoring of cloud properties (cloud cover, effective temperature, optical thickness, ice\water phase and effective particle size) day and night, as well as tropospheric water vapor, ozone and temperature.

EOSP (Earth Observing Scanning Polarimeter) covers the solar spectrum from the near ultraviolet (0.4 μm) to the near infrared (2.25 μm) in 12 spectral bands, obtaining global maps of the radiance and polarization with a spatial resolution of 8 km at the subsatellite point. Its unique contributions are accurate global distribution and physical properties of tropospheric aerosols (optical thickness, particle size and refractive index) and precisely calibrated surface reflectance, as well as an independent measurement of detailed cloud properties.



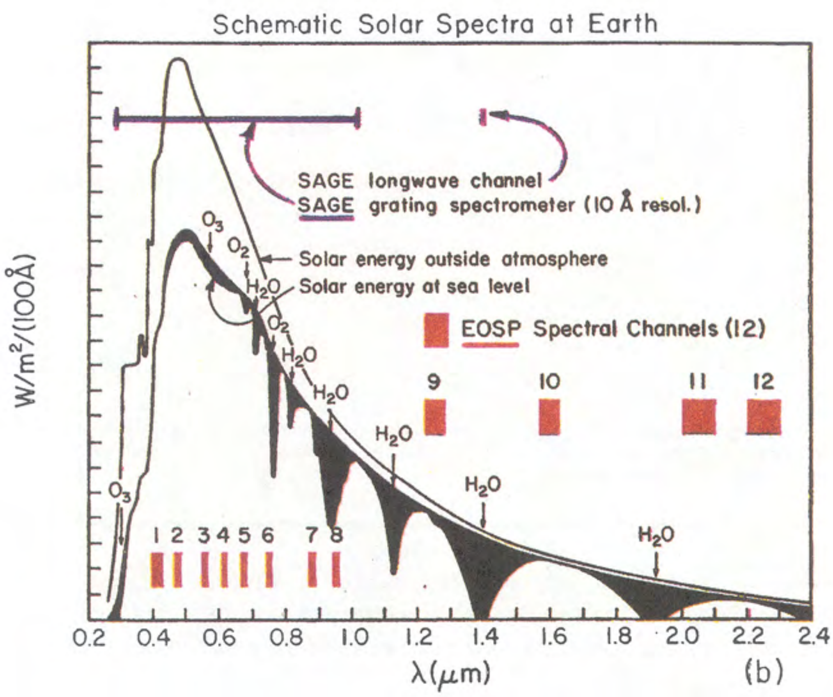


Fig. 7.1. (a) Example of terrestrial thermal spectrum, obtained by the Nimbus-3 IRIS instrument over the Sahara desert. MINT will have a somewhat broader spectral coverage, 250-1700 cm^{-1}, and higher resolution (2 cm^{-1}). (b) Location of the EOSP and SAGE III spectral channels, relative to a typical spectrum of solar radiation.

TABLE 7.2. **Climsat Sensors**

SAGE III	EOSP	MINT
Earth-limb scanning grating spectrometer, UV to near IR, 10 Angstrom resolution.	Cross-track and along-track scans of radiance and polarization, 12 bands near UV to near IR.	Michelson interferometer, 2 cm^{-1} resolution from 6μm to 40μm; nadir viewing by 2×3 array of detectors.
IFOV=30 arcsec (~0.5 km); inversion resolution 1-2 km.	IFOV=12 mrad (8 km at nadir).	IFOV=12 mrad (8 km from 650 km altitiude).
Yields profiles of T, aerosols, O_3, H_2O, NO_2, NO_3, OClO - most down to cloud tops.	Yields aerosol optical depth, particle size and refractive index, cloud optical depth and particle size, and surface reflectance and polarization.	Yields cloud temperature, optical depth, particle size and phase, temperature, water vapor and ozone profiles and surface emissivity.
Mass: 35 kg	Mass: 19 kg	Mass: 20 kg
Power (mean/peak): 10/45 W	Power (mean/peak): 15/22 W	Power (mean/peak): 14/22 W
Mean Data Rate: 0.45 Tbpy*	Mean Data Rate: 1.6 Tbpy*	Mean Data Rate: 0.7 Tbpy*
Cost: About $20M for first copy, About $10M each additional copy	Cost: About $20M for first copy, about $10M each additional copy	Cost: About $20M for first copy, about $10M each additional copy

* Tbpy = Terabits/year; Mission Comparison: ISCCP = 0.2 Tbpy; CLIMSAT = 5 Tbpy; EOS = 2500 Tbpy [one Terabit is approximately 1000 tapes (6250 bpi) per year]

SAGE III (Stratospheric Aerosol and Gas Experiment III) observes the sun and moon through the Earth's atmosphere obtaining an extinction profile with very high vertical resolution. SAGE III uses the same grating spectrometer as its immediate predecessors, but, unlike them, it records the spectrum on a continuous linear array of detectors, yielding a spectral resolution of 10 Å (10^{-3} μm) from 0.29 μm to 1.02 μm. It also adds a detector at 1.55 μm. SAGE III will provide absolutely calibrated profiles of stratospheric aerosols, stratospheric water vapor, and ozone, extending and improving upon predecessor data.

Table 7.2 summarizes specific technical data on each of the three instruments, and Table 7.3 lists several characteristics which apply to the complement of the three instruments. All of these six characteristics are essential for Climsat to meet its scientific objectives while requiring only moderate resources.

Perhaps the most crucial characteristic of the Climsat instruments is that they are all self-calibrating to very high precision. The SAGE calibration is obtained by viewing the sun (or moon) just before or after every occultation. MINT records its interferogram on a single detector, thus obtaining very high wavelength-to-wavelength precision. EOSP interchanges the roles of its detector pairs periodically by using a stepping half-wave retarder plate, calibrating polarization to 0.2% absolute accuracy. The EOSP radiance calibration is based primarily on internal lamps with a demonstrated stability of better than 2% per decade, implying a decadal precision for surface reflectivity of better than 0.002 for a surface reflectivity of 0.1. This radiance calibration exceeds that of operational satellites by a factor of about five (Brest and Rossow, 1992).

All three Climsat instruments are based on space-proven predecessors, with incremental but significant enhancements in capability, incorporating recent advances in detector and electronic technology. Each of the three instruments has a predecessor with a lifetime in space exceeding 10 years. Although it is not possible to precisely state instrument costs at this early stage of definition, two of the three instruments have gone through phase A/B studies in the EOS program, which produced government estimated costs of $15M to $20M per instrument for the first copy, and substantially lower costs for additional copies.

TABLE 7.3. **Climsat Instrument Characteristics**

1. **Cover Solar and Thermal Spectra:** encompass surprises
2. **Self-Calibrating:** yields the high precision required for monitoring small changes
3. **Small:** fits on Pegasus-class launcher
4. **Proven Technology:** space-tested heritage
5. **Long-Life Capability:** predecessors all have demonstrated lifetimes >10 years
6. **Inexpensive**

Figure 7.2a provides a size comparison of different spacecraft, showing that Climsat is very small in comparison to other familiar spacecraft. The small size and mass of Climsat allow it to fit on a Pegasus-class launcher (Fig. 7.2b). One advantage of this small size is that the cost of a Pegasus launch is only about $10M.

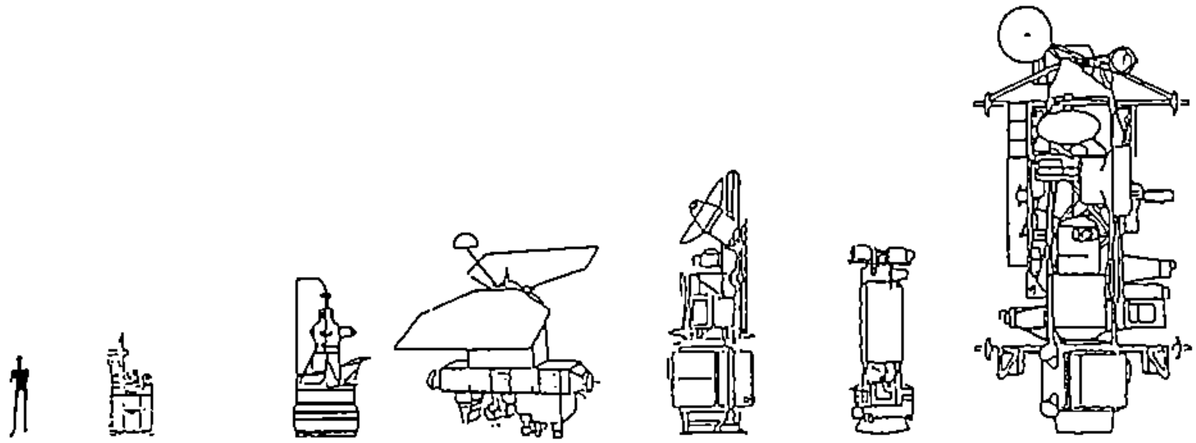
Measurement Accuracies

We consider two criteria for specifying the accuracies with which climate forcings and feedbacks need to be monitored. The first criterion is based on the plausible changes of the forcings and feedbacks during the next 20 years, as estimated in Section 3. At minimum, we would like a monitoring system capable of detecting such changes. The second criterion is the more demanding desire to determine quantitatively the contribution of every forcing and feedback to the planetary energy balance. We define a significant global mean flux change as 0.25 W/m^2 or greater, based on the consideration that anticipated increases of greenhouse gases during the next 20 years will cause a forcing of about 1 W/m^2. The accuracy requirements resulting from these two criteria are listed in the second and third columns of Table 7.4.

The capabilities of the proposed Climsat mission depend on the instrumental accuracies and precisions, and also on the sampling provided by the Climsat orbits. The instrumental capabilities are discussed in Sections 8-10 and the sampling in Sections 11-12. Reliable determination of the ultimate capabilities is extremely difficult, and further simulations of instrument performance, data inversion techniques, and sampling studies will be pursued. Sampling studies for the stratospheric quantities, for example, are hindered by inadequate knowledge of small scale spatial variability of the parameters being measured. Our present estimates of Climsat capabilities are given in the fourth column of Table 7.4 for regional (1000 km by 1000 km), seasonal (3 month) averages and in the fifth column for global decadal change. Generally the sampling is not a factor in determining the global decadal change, but it does influence the ability to determine regional seasonal change.

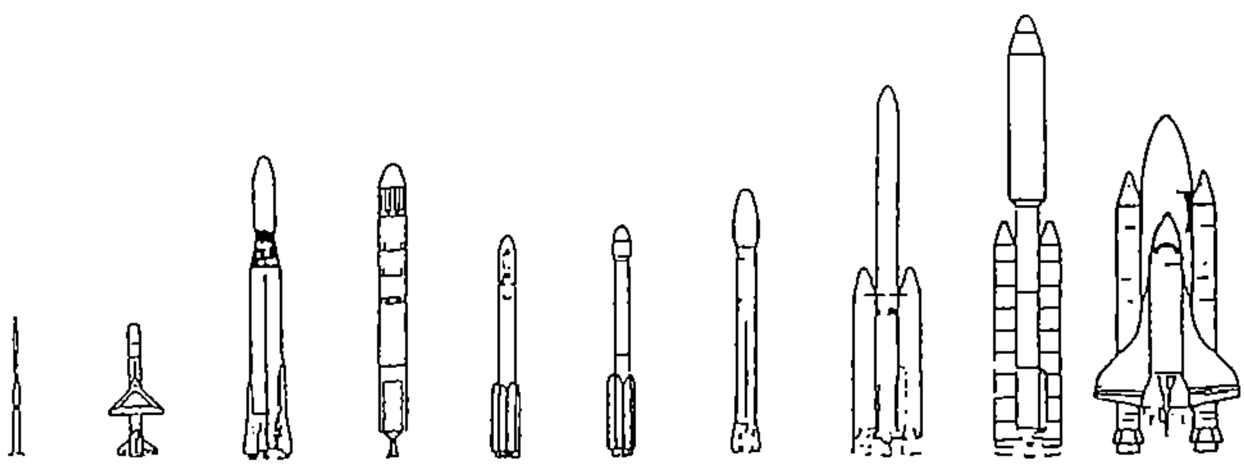
It is clear that, in general, Climsat is capable of measuring the changes of climate forcings and feedbacks projected as being plausible during the next 20 years. The more difficult criterion, quantifying the flux changes to 0.25 W/m^2, can also be achieved readily for all the climate forcings except aerosol induced cloud changes. This latter forcing can be measured in the regions of (measured) large aerosol changes, which may allow an inference of the corresponding global forcing. It appears that Climsat may be just marginally capable of measuring most of the feedbacks, mainly cloud parameter changes, to the 0.25 W/m^2 criterion. Direct measurement of cloud optical thickness change to this accuracy does not appear to be achievable. The alternative of measuring the corresponding cloud albedo changes over decades is also just outside the capability which is proven for the EOSP calibration lamps on the basis of planetary flight experience. We emphasize that the accuracies considered here are several times better than those of current meteorological satellites, which are already capable of detecting some interannual changes (Ardanuy *et al.*, 1992).

Size Comparisons of Several Spacecraft



	CLIMSAT	NIMBUS-7	ERBS	LANDSAT	ATN	UARS
Mass:	250 kg	1,021 kg	2,225 kg	1,727 kg	1,909 kg	6,736 kg
Diameter:	1.4 m	1.6 m	1.6 m	2.2 m	1.9 m	4.3 m
Height:	2.8 m	3.6 m	3.8 m	5.6 m	4.2 m	9.8 m
Payload:	75 kg	303 kg	100 kg	318 kg	361 kg	2,238 kg

Payload Weight (tons) to Low Earth Orbit



SCOUT	PEGASUS	ATLAS H	TITAN II	DELTA 3820	DELTA II	ATLAS G CENTAUR	TITAN 34D	TITAN IV CENTAUR G	STS
0.2	0.3	2.0	2.3	3.4	5.3	6.1	13.9	17.7	29.5

Fig. 7.2. (a) Size comparison of the proposed Climsat spacecraft with some familiar spacecraft. ATN is similar to polar orbiting meteorological spacecraft. (b) Payload comparison of different launchers; Climsat requires a Pegasus-class capability.

TABLE 7.4. **Comparison of estimated Climsat measurement accuracies with changes of forcing and feedback parameters anticipated on a 20 year time scan and with the parameter changes required to yield a flux change of 0.25 W/m².**

Forcing or Feedback	Plausible 20 Year Change	Global Change Required to Yield ΔFlux = 0.25 W/m^2	Climsat Accuracy Estimated for Regional/ Seasonal Mean	Climsat Accuracy Estimated for Global Decadal Change
Ozone	Altitude and Height dependent	10% of O_3 at 15-20 km	10%	3%
Stratospheric H_2O	$\frac{\Delta q}{q} = 0.3$	0.25	0.10	0.03
Stratospheric Aerosol	$\Delta\tau = 0.04$	0.01	0.02	0.002
Tropospheric Aerosol	$\Delta\tau = 0.04$	0.01	0.02	0.005
Total Solar Irradiance	0.1 - 0.3%	0.1%	not on Climsat, but ACRIM, if flown continuously, could readily achieve the needed accuracy	
Surface (land) Reflectivity	0.01 (land)	0.006 (land)	0.01	0.003
Tropospheric H_2O				
upper	$\frac{\Delta q}{q} = .10$	0.02	0.05	0.03
lower	$\frac{\Delta q}{q} = .04$	0.02	0.03	0.02
Cloud cover				
cirrus	$\Delta C =$ 0.03 (regional)	0.004	0.02	0.004
stratus	$\Delta C =$ 0.03 (regional)	0.003	0.02	0.004
Cloud Top				
temperature	$\Delta T = 1$ K	0.4 K	1 K	0.3 K
pressure	$\Delta p = 12$ mb	5 mb	15 mb	5 mb
Cloud Optical Depth				
cirrus	$\Delta\tau = 0.1$	0.02	0.1	0.05
stratus	$\Delta\tau = 1$	0.07	0.5	0.2
Cloud Particle Size (water)	$\Delta r = 1\ \mu m$	0.2 μm	0.5 μm	0.2 μm

In summary, Climsat would be capable of detecting plausible decadal changes of those climate forcings and feedbacks which it addresses. In most cases, if not all, Climsat can quantify the forcings to the high precision (0.25 W/m²) desired to help interpret global climate change. Climsat is also close to achieving that level of precision for the climate feedbacks. Thus the feedback measurements should be of great value as a complement to the usual approach of analyzing feedbacks, which consists of a combination of modeling and process observations, the latter being used to improve the models iteratively.

Complementary Monitoring Requirements

Although Climsat can provide many of the missing climate forcings and feedbacks with the required accuracies, certain other monitoring is needed to complete the full set of data requirements. Complementary long-term monitoring requirements are summarized in the final column of Table 7.1.

The most crucial requirement is for long-term monitoring of the sun. The sun provides the ultimate drive for the Earth's climate, including the global thermal energy cycle. A plausible case has been made that solar irradiance changes might be responsible for climate changes such as those characterized by the Little Ice Age (Eddy, 1976), which may require solar changes of as little as several tenths of a percent (Wigley, 1988; Wigley and Kelley, 1990). Precise monitoring of the total solar irradiance during the past decade (Willson and Hudson, 1991; Hoyt *et al.*, 1992) confirmed the existence of significant variations of solar irradiance, of the order of 0.1 percent over the last 11 year solar cycle. It is essential that this fundamental measurement be continued. There must be an overlap of the successive monitoring instruments, because it is not possible to obtain sufficient absolute accuracy of the irradiance (Fig. 2.8; Lean, 1991). The UARS mission (Reber, 1990) includes ACRIM II, which precisely monitors total solar irradiance, but it is very important to make immediate plans for prompt flight of another ACRIM or its equivalent.

It is also necessary to monitor the spectrum of the solar irradiance. The climate forcing due to solar change is entirely different if the change occurs at wavelengths absorbed in the upper atmosphere, as opposed to wavelengths which reach the troposphere. Furthermore changes in ultraviolet irradiance may cause an indirect climate forcing by altering the abundances of greenhouse gases such as ozone (Chandra, 1991; Stolarski *et al.*, 1991). The UARS mission includes two instruments which monitor the solar spectral irradiance in the ultraviolet region, where large variability is known to occur (Rottman, 1988), but plans for a follow-up are urgently needed. Total and spectral irradiance monitors would both appear to be prime candidates for flight on small satellites.

Several of the parameters which Climsat can monitor require complementary detailed measurements from ground stations, specifically ozone, tropospheric aerosols and tropospheric water vapor. The change of the ozone profile in the upper troposphere and lower stratosphere is difficult to measure accurately from space, because that region lies below the bulk of the ozone. Although SAGE III will be more capable than predecessor instruments in this regard, it is also important to have monitoring from a number of well placed ground stations. If the plans for the Network for Detection of Stratospheric Change (Kurylo and Solomon, 1990) and plans for tropospheric monitoring (Prinn, 1988) are implemented, and if the Climsat mission is implemented, monitoring of the ozone profile should be adequate for the purpose of defining ozone climate forcing.

Similarly, monitoring of tropospheric aerosols from space with the required high precision is new. It will be important to have detailed aerosol "ground truth" monitoring and periods of special detailed study at a number of continental and marine stations, as is being discussed (Charlson, Schwartz, private communication). Finally, monitoring of upper tropospheric water vapor from space needs to be supplemented by improved radiosonde measurements, which requires introduction of instruments with improved accuracy and calibration (Gaffen *et al.*, 1991).

Community Involvement

Success of such a climate monitoring system can be attained only if there is broad involvement of the scientific community. Rapid production and broad availability of the data products is an essential requirement. For the data to be fully effective, it also will be crucial to provide resources to the scientific community, through an announcement of opportunity process, to carry out studies with the data. Representatives of the community must be involved in the design of the monitoring system at the earliest stages. Thus if a Climsat project is approved for further development, there should be a Dear Colleague letter or Announcement of Opportunity to solicit involvement of representative members of the community in the further definition and implementation of the mission.

It is recognized that relevant scientific and engineering expertise are distributed in the private sector, universities and the government. Thus one effective way to initiate a satellite mission may be via consortia responding to a request for small satellite proposals. A proposal selected through this mechanism could potentially reduce procurement delays. This is particularly important, because only if the project development time is minimal, say four years or less, will it be possible to fill the impending data gaps for key climate parameters. The prospect of prompt results is also important for attracting the best scientists to participate.

Relation to Climate Process and Diagnostic Studies

Long-term monitoring of global climate forcings and radiative feedbacks is, of course, only a portion of global climate measurements (cf., USGCRP, 1993). There is a great need for monitoring of climate diagnostics and for detailed measurement and analysis of a number of climate processes, especially relating to the oceans, clouds, precipitation, and fluxes between the surface and the atmosphere. It is important that measurements of these climate diagnostics and processes proceed apace with the long-term climate monitoring of climate forcings and radiative feedbacks. The combination of improved knowledge of changing climate forcings and feedbacks together with improved understanding and modeling of climate processes is required to obtain predictive capability of future climate.

The rate at which the climate system responds to a change of climate forcing depends upon how rapidly a heat perturbation mixes into the ocean. Also, it is essential to understand how ocean circulation may change in response to atmospheric changes (Broecker, 1987). The WOCE (World Ocean Circulation Experiment) program (WCRP, 1986), especially if it is continued and expanded, promises to improve our understanding of ocean circulation and its relation to atmospheric climate change. Acoustic tomography, in particular the proposed near-global expansion of the Heard Island experiment (Munk and Forbes, 1989), appears to have exciting potential for monitoring heat uptake by the ocean on decadal time scales. This must be complemented by a continuing series of altimetry and scatterometer space missions to measure surface winds and ocean currents.

Clouds are probably the most uncertain climate feedback. In addition to monitoring of possibly small decadal cloud changes, it is important to make detailed observations which allow us to understand and model cloud processes better. A recent proposal to fly the CERES instrument on a small satellite in formation with a NOAA polar orbiting meteorological satellite would provide an improved ability to study the relation of clouds and the earth's radiation budget. In addition, much more detailed studies should be possible with the EOS mission, since almost all of the EOS instruments have some cloud measurement objectives.

Precipitation is a climate diagnostic of great practical importance. Moreover, changes of precipitation can complicate attempts to interpret long-term temperature changes, because of the latent heat associated with evaporation and precipitation. Although there is no expectation that rain rates will be monitored with a precision comparable to that of the radiative forcings and feedbacks, it is important that rainfall monitoring be advanced as much as practical, to improve the simulation and prediction capability of climate models. Thus the TRMM mission (Simpson *et al.*, 1988) planned for 1998 should be just the beginning of a rainfall monitoring satellite series, with measurement capabilities and coverage that improve with time.

Fluxes between the atmosphere and the earth's surface of energy, momentum, water, carbon, and other substances are intimately involved in the functioning of the earth's climate. Many measurements related to these fluxes will be obtained by EOS, and these data should contribute toward improved modeling of climate processes. Many of these data will be more valuable if they are accompanied by accurate measurements of near surface winds; this requires advances in instrument technology and may be a good candidate for a focused small satellite mission. Regional ground-based and ocean field studies are also essential for improved understanding of fluxes.

TABLE 7.5. **Why equivalent monitoring data cannot be obtained from EOS.**

1. EOS does not include all of the Climsat instruments or an adequate equivalent. EOSP is not confirmed for flight, but may fly on the second AM polar platform. SAGE is not confirmed for flight, but may be flown on its own satellite in an inclined orbit. The very high wavelength-to-wavelength precision of the Michelson Interferometer using a singe, passively cooled detector without scanning is crucial for obtaining the required accuracy. AIRS on EOS uses separate detectors for each wavelength, requiring individual calibrations, is actively cooled and does not cover the thermal spectrum.
2. Proposed EOS flights of EOSP and SAGE and the flight of AIRS do not provide the required sampling and coverage, since only one copy of each instrument is flown in a single orbit. Instruments on the polar orbiter provide a diurnally biased global coverage. SAGE in an inclined orbit does not provide coverage of the polar regions.
3. The monitoring datasets must be contemporaneous, continuous and long-term (several decades), since the climate system integrates the forcings. Current EOS plans do not insure contemporaneous flights of these instruments, the lack of "hot spares" will probably preclude continuity. If one of these small instruments failed on an EOS platform, would the whole platform be replaced?
4. It is not economical to add the Climsat instruments to a large satellite. Flight of a few small instruments is better suited to a small satellite and avoids "all eggs in one basket".
5. A two satellite system with identical instruments can guarantee overlapping observations for cross-calibration if satellites that fail are replaced promptly, which is critical for long-term data precision. EOS plans do not include such cross-calibration.
6. It is realistic to maintain the low cost, small Climsat system over several decades. Continuous monitoring with EOS is prohibitively costly.
7. Even if all the Climsat instruments were added to the EOS platforms, they would be unlikely to command the priority essential to success (regarding launch dates when there are funding shortfalls, mission operations when there are power or other constraints, etc.)

Complementarity to EOS

We anticipate that the acquisition of high precision time series of climate forcings and radiative feedbacks will increase the demand for detailed measurements of climate processes. The forcing and feedback data would thus play a role in study of the thermal energy cycle somewhat analogous to that which Keeling's CO_2 monitoring played for study of the carbon cycle. EOS, by providing high resolution detailed observations, should be nicely complementary to Climsat monitoring.

The question naturally arises as to whether the climate forcing and feedback information could not be extracted from the EOS observations. The reasons that this is not the case are summarized in Table 7.5. All of the Climsat instruments or their equivalents are not included on EOS, and those which are do not have the orbits and sampling required to yield the necessary precision of the forcings and feedbacks. In particular the precessing inclined orbiter is critical to the elimination of diurnal measurement bias. The absence of "hot spares" for the EOS spacecraft makes continuity of the data unlikely, a crucial drawback for climate forcing time series. Also the two satellite Climsat approach is needed for instrument cross-calibration, which is critical to the long-term data precision.

It should also be noted that, if Climsat should be approved for implementation, it would relieve EOS of certain burdens, such as the need for a SAGE inclined orbiter and EOSP on the AM-2 platform. These savings could help keep the EOS budget within congressionally imposed constraints and free resources for other purposes, assuming that Climsat were funded outside the EOS budget.